Does Pacific halibut behavior correspond to regular environmental cycles?

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Introduction

- Pacific halibut (*Hippoglosus stenolepis*) is an important resource for subsistence, commercial, and recreational fishers throughout the Gulf of Alaska and the Bering Sea
- Behavior patterns of animals often follow the same pattern as fixed periodic environmental cycles (tidal, diel, lunar, etc.), resulting in periodic behavior
- Understanding of halibut behavior in its natural environment may inform its management by improving knowledge about susceptibility to capture, thus increasing accuracy of stock assessments
- UAF and International Pacific Halibut Commission scientists have studied halibut behavior using depth-sensing electronic tags (Fig. 1)
- I hypothesize that Pacific halibut behave periodically on timescales that correspond to those of periodic environmental cycles
- The objective of the study was to examine existing depth data for recorded periodic behavior and assess how it changes throughout the seasons

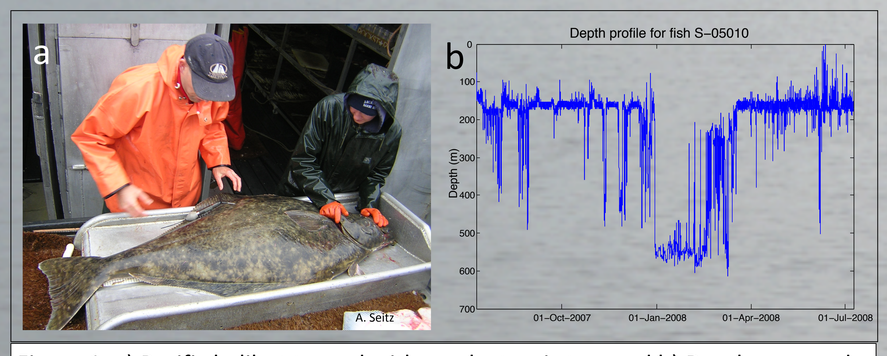

Figure 1. a) Pacific halibut tagged with an electronic tag, and b) Depth meaured every minute by a PSAT tag attached to a Pacific halibut.

Methods

- 39 datasets containing depth measurements recorded every 0.5, 1, or 2 minutes by an electronic tag attached to a Pacific halibut
- Two methods used for analyzing the data for periodic behavior
  1. Periodogram analysis, computed using R and MATLAB
     - A periodogram is a value (with units of meters) indicating how well data repeats itself over a fixed number of data points
     - I calculated periodograms at regularly spaced data intervals and for a range of periods and plotted the values on a surface of time and period
     - Peaks values are indicators of time-scales of highly periodic behavior for certain sections of tag data
  2. Continuous wavelet transforms used primarily, computed in MATLAB
     - A wavelet is a small oscillating curve ψ(t) which quickly decreases to zero, and can be scaled (made longer or shorter along the time axis) and shifted (slid along the time axis)
     - A continuous wavelet transform is a function that returns unitless wavelet coefficients in place of depth measurements
     - Each wavelet coefficient tells how similar the depth data surrounding a central point are to a given scale of a mother wavelet, comparing the shape of the wavelet to that of the halibut depth data
     - Wavelet coefficients are plotted on a surface of time and wavelet scale, with coefficients at lower wavelet scales receiving higher weight to prevent those at higher scales from dominating
     - For depth measurements recorded every 0.5 and 2 minutes, wavelet scales were corrected to be equivalent to those for 1 minute depth measurement; thus, the units for scales is minutes
     - Two mother wavelets were used:
       1. The morlet wavelet (Figure 2a) oscillates before settling to zero, allowing matching of adjacent periods (*sensu* Subbey et al., 2008)
       2. Mexican hat wavelet (Figure 2b) also used because some fish behaviors may match its pattern
- Resting periods in the tag data and hypothetical random data used as control

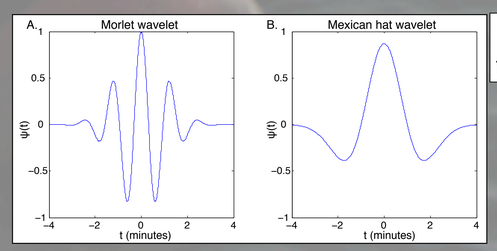

Figure 2. Mother wavelets used for wavelet analysis in this study

Acknowledgements

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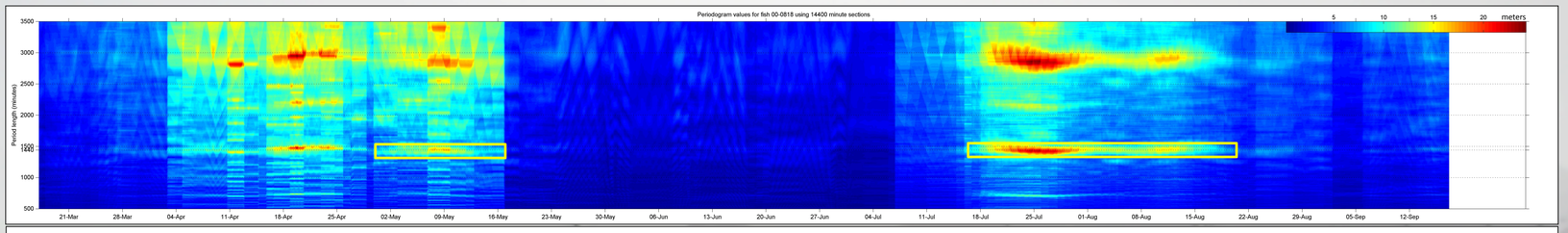

Figure 3. Periodogram map of fish 00-0818 for 10 day (14400 min) sections of tag data (plotted at their first point) and periods of 500 to 3500 min (0.35 to 2.43 days). This periodogram analysis is of the same fish as the wavelet analysis directly below in Fig. 4A. The figure reveals that depth-specific behavior occurred with a regular periodicity of 1440 min (1.00 day) during parts of the year (yellow boxes). The peak values near 2880 min are expected as a multiple of 1440 min.

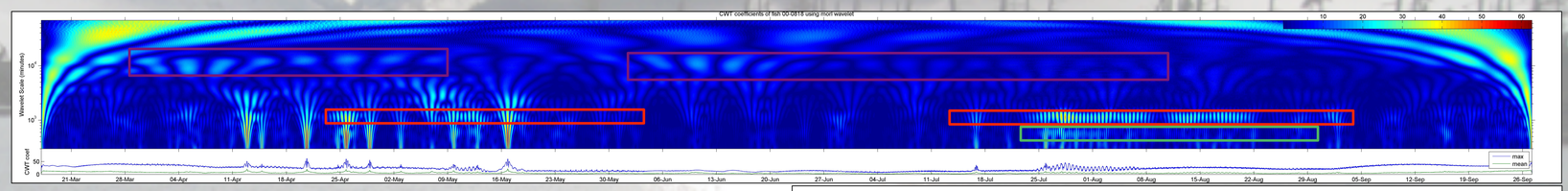

Figure 4A. Pacific halibut wavelet coefficient map for fish 00-0818, complementary to the periodogram analysis of 00-0818 above in Fig. 3, showing large variations in the periodicity. Coefficients scaled by 1/sqrt(wavelet scale) to allow low scales to be visible. Red boxes represent areas where wavelet scales correspond to behaviors that occur with one-day periodicity, green boxes correspond with wavelet scales that detect either a half day (720 minutes) or one tide (745 minutes) periodicity, and purple boxes are sections where larger scale cycles may be detected (possibly lunar cycles)

Results

- Preliminary periodogram analysis results
  - Halibut displayed depth-specific behaviors that occurred with a regular diel periodicity (Fig. 3)
  - Detected tidal oscillation in inactive fish
- Preliminary wavelet transform results
  - Wavelet coefficient maps reveal times when fish behavior had regular periodicity, when fish were inactive, and when fish were active but not behaving periodically
  - Identification of wavelet scales which repeatedly have peaks, for further analysis by determining the wavelength (period) of the signal
    - Intermediate scales (Fig 4A,B, red boxes), related to diel oscillations because the period of this signal is 1.00 day, with the fish occupying different depths during night and day
    - Lower scales (Fig. 4A,B, green boxes), possibly related to tidal oscillations
    - Higher scales (Fig. 4A,B, purple boxes), seem to be less periodic, but may be related to lunar cycles

Discussion

- Results have shown that Pacific halibut depth–specific behavior does follow periodic environmental cycles, including diel (24 hour) cycles
- The degree to which halibut display periodic behaviors at several scales varies throughout the year
- Halibut biomass measurement (important for sustainable management) is completed indirectly from standardized longline surveys and catch reporting
- Our study provides insight into some predictable halibut behaviors that may make them unsusceptible to catch or surveying
- Knowledge of halibut behaviors elucidated by this tag data analysis, once quantified, may aid in stock assessments

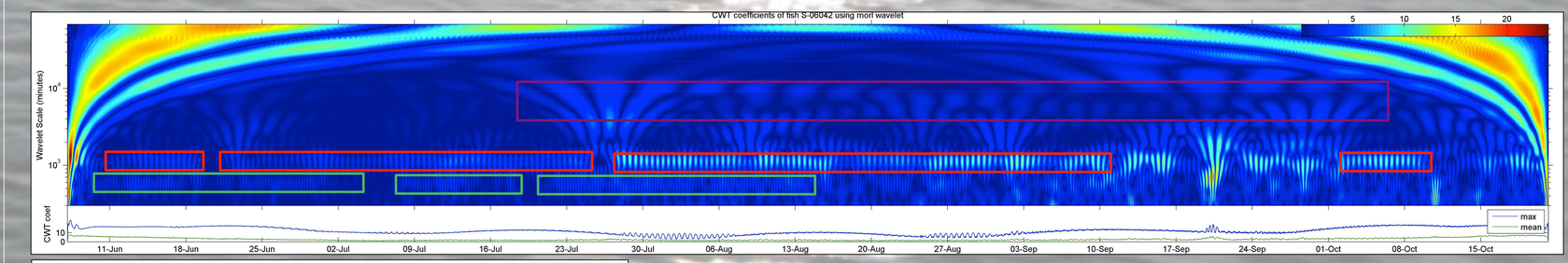

Figure 4B. Pacific halibut wavelet coefficient map for fish S-06042, which exhibited relatively consistent periodic behavior for an extended time. See description in caption for Fig. 4A for plot details.

Further Research

- Potential tidal and lunar cycles are still under investigation
- Continue working through wavelet analysis of all available tag datasets
  - Current research has largely been qualitative, exploring methods and possible meanings of observed signals
  - Switch focus to quantitative analysis of periods
- Apply the periodogram analysis to more halibut tag datasets, especially areas of interest identified by wavelet analysis
- Assess how halibut change periodic behavior when changing habitat as in Seitz et al. (2011)
- Evaluate and define methods that are useful for analysis of future Pacific halibut tagging projects, or for other species such as Atlantic halibut

References

Seitz AC, Loher T, Norcross BL, Nielsen JL, 2011. Dispersal and behavior of Pacific halibut *Higgoglossus stenolepis* in the the Bering Sea and Aleutian Islands region. *Aquatic Biology*, 12: 225-239.

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